Tune/Chromaticity/Coupling Results in Light of LHC Requirements

Peter Cameron

Outline

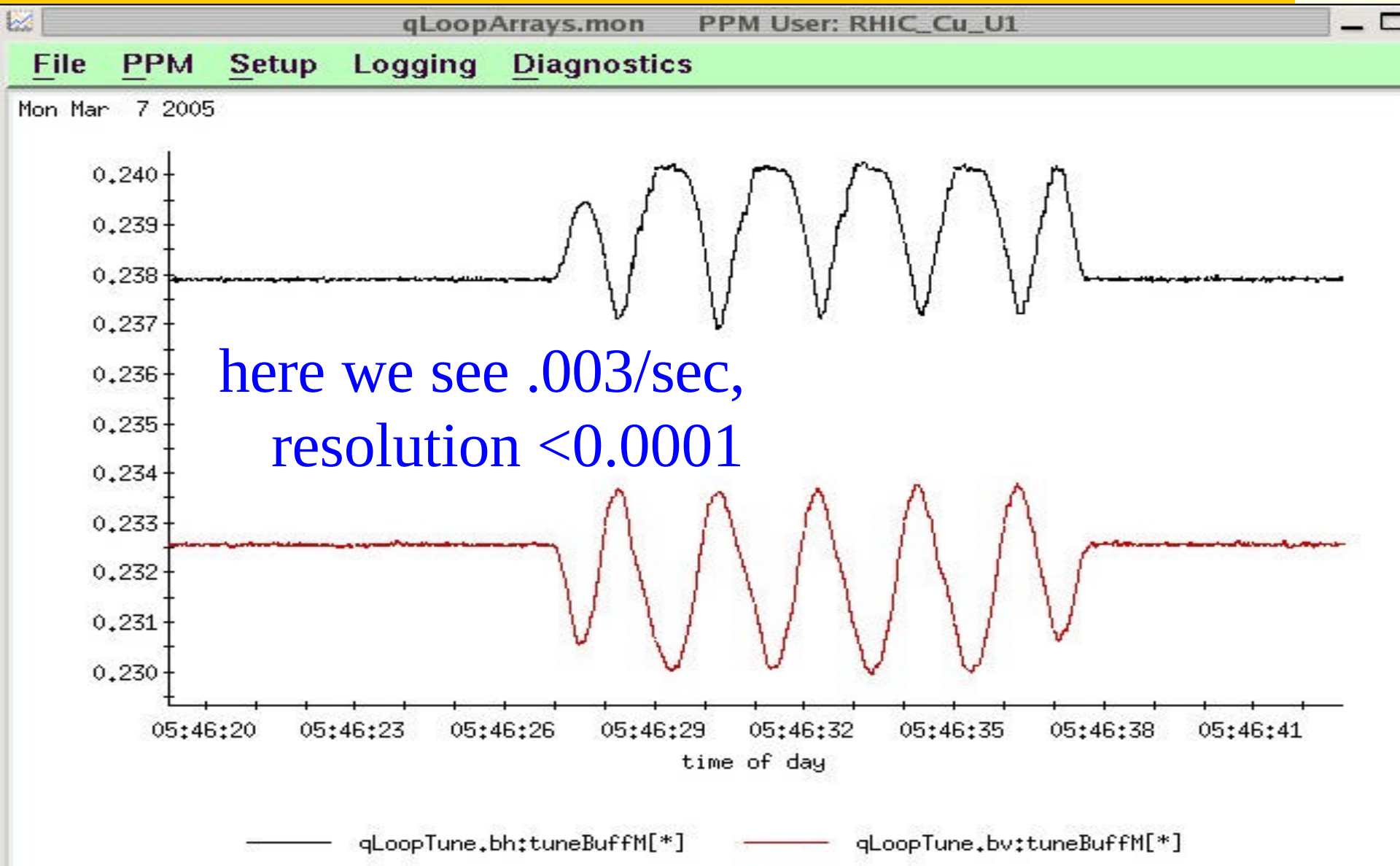
- **Tune - Can we meet the spec?**
- Chrom - Can we meet the spec?
- Coupling - Is the spec adequate to our needs?
- Emittance Growth - Can we meet the spec?
- 60Hz - Can a solution be found?
- Damper - Can we live underneath it?
- Orbit Feedback - Can we live on top of it?

Commissioning - Summary of Requirements

- First Beam
  - Individual pilot bunches of ~5×10^{9} ppb
  - Q and Q' constraints relaxed
- First Physics Run (end of commissioning)
  - 43 on 43 bunches of 3-4×10^{10} ppb

Commissioning (first physics)	**Drift Rate (snap-back)** (Unit per sec for ~30sec)		**Tolerance**	**Requested Accuracy**	**Correction Rate** (Hz)
	Max	80% Pred	Inj / ramp	±	80% Pred
Orbit (mm)					**<1**
Tune (´ 10^{-3})	2.8	0.6	~10	3	**0.1**
Chromaticity (Q_X)	3.8	0.8	5	2.5	**0.3**

Skew Modulation



Normal Operation - Summary of Requirements

Normal Operation	Drift Rate (snap-back) (Unit per sec for ~30sec)		Tolerance	Requested Accuracy	Correction Rate (Hz)
	Max	80% Pred	Inj / ramp		80% Pred
Orbit (mm)					**<1**
Tune ($\Delta 10^{-3}$)	2.8	0.6	3	0.75	**0.3**
Chromaticity (Qx)	3.8	0.8	1	0.5	**1**

- Tolerance on Chromaticity reduced by a factor of 5
- Requested accuracy better than 1 unit
- Correction rate of 1Hz required during snap-back
  - Implies a measurement rate >1Hz

Tune Conclusion

- We can meet the spec
- Attention must be given to feedforward, to minimize required correction strength in succesive ramps
- Interface between correction strength buffer from latest ramp to ramp manager for next ramp must be in place - this is a CERN responsibility

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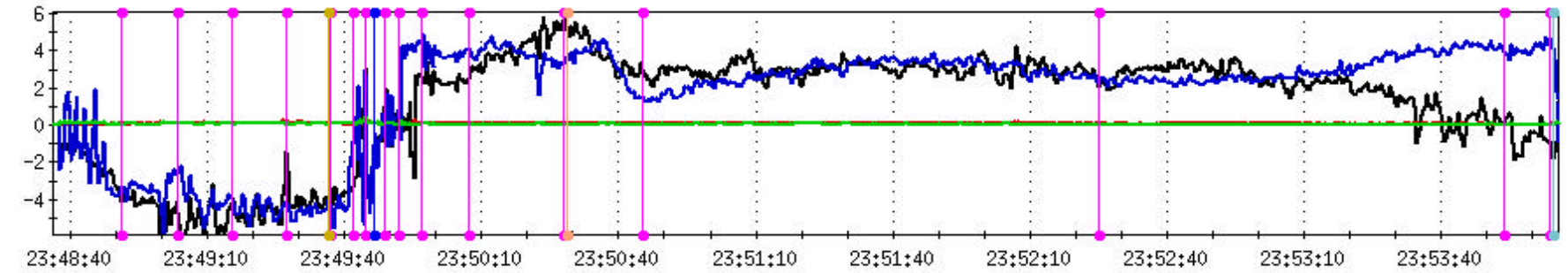
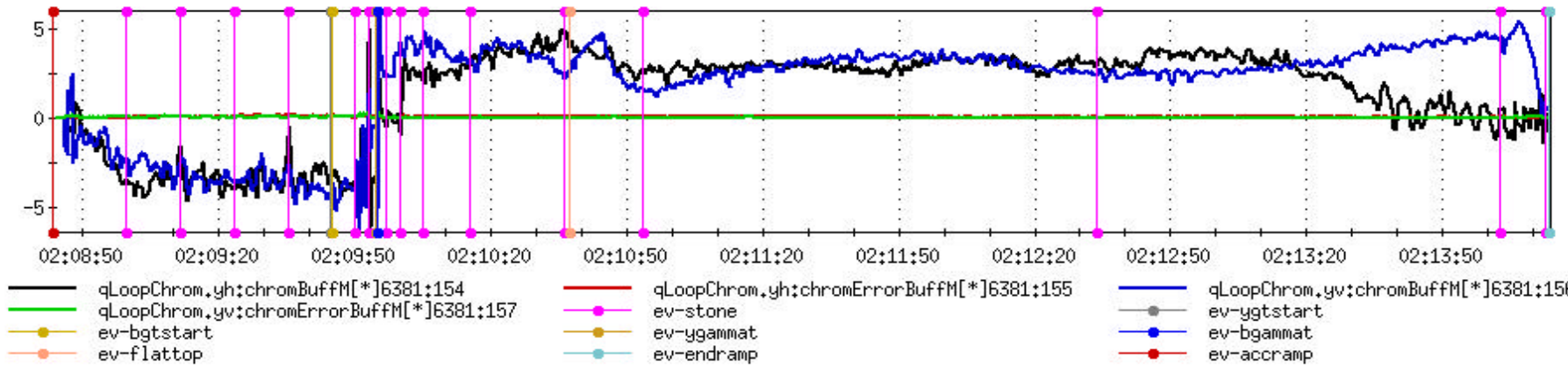
Chromaticity Effect on PLL

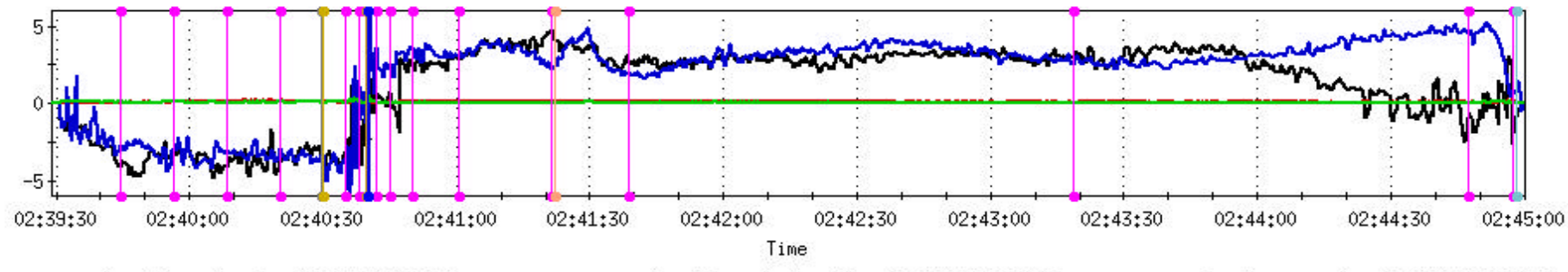
- Conclusion from chromaticity study (and years of experience with beam) is that 245MHz PLL tune measurement comfortably copes with a large range of chromaticity (resonantly excites low δp subset of momentum distribution)
- Chromaticity control is not an issue for 245MHz PLL tune measurement and tune/chrom feedback – further study required for baseband system, but we expect similar behavior
- Chromaticity control is an issue primarily in the usual operational sense – line broadening and resonance overlap

Mon Mar 07 23:48:36 - Tue Mar 08 02:45:00

Window Event







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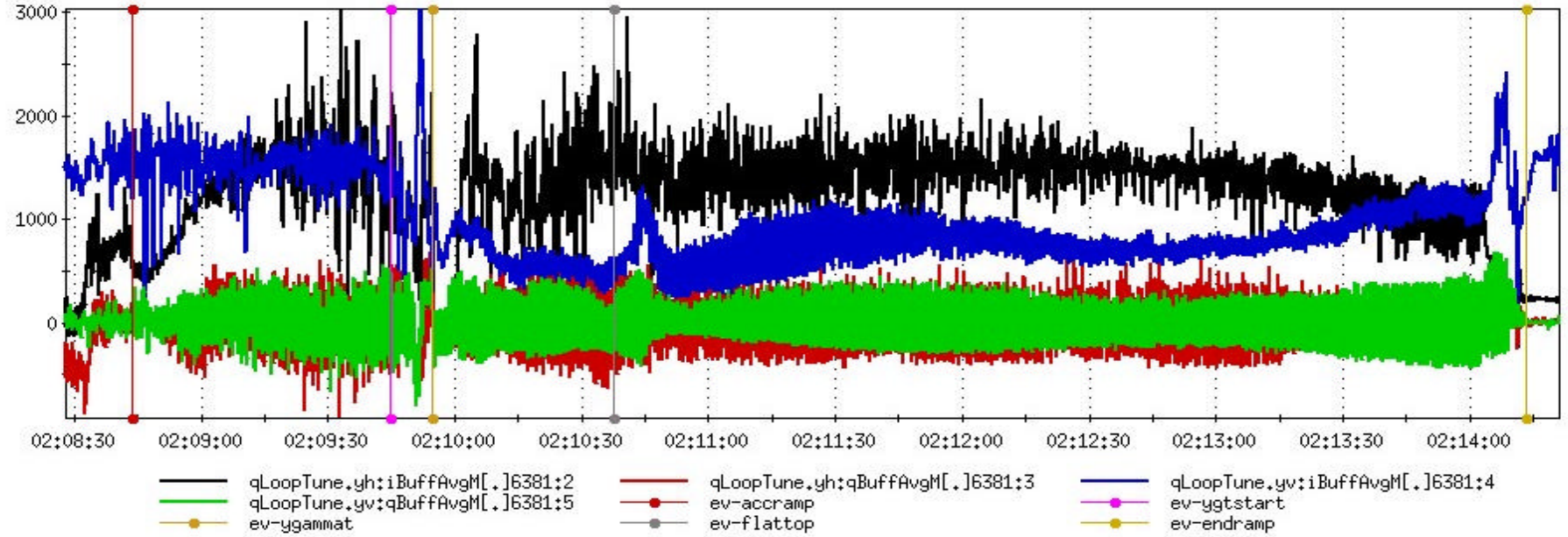

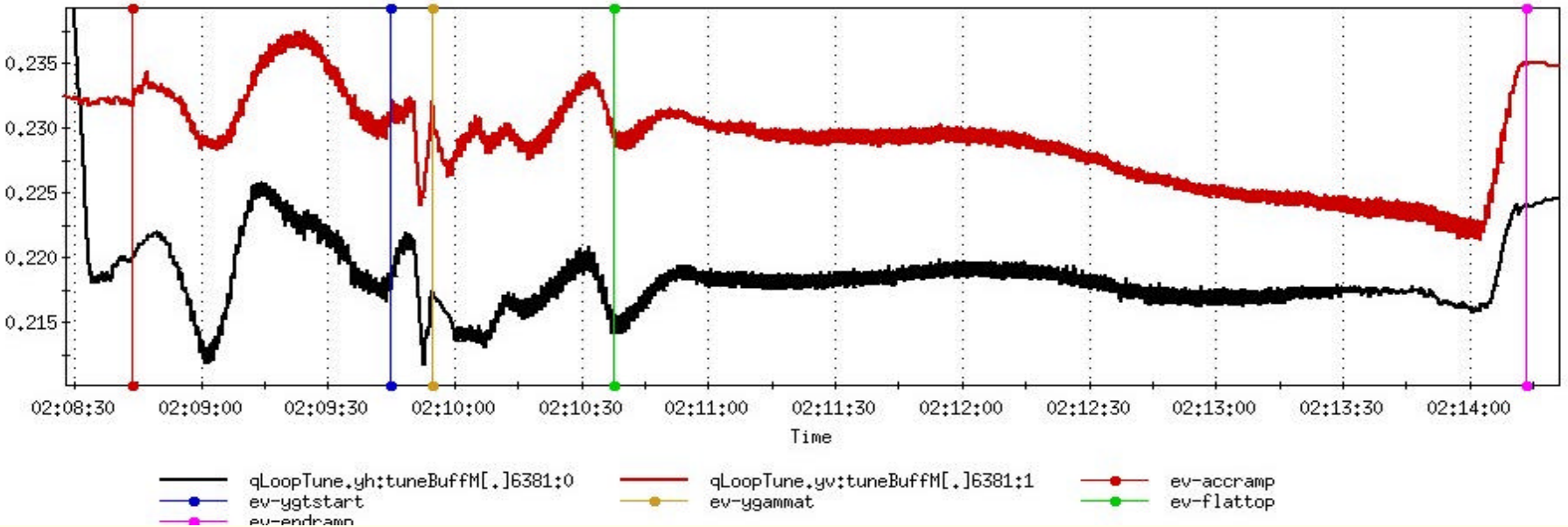

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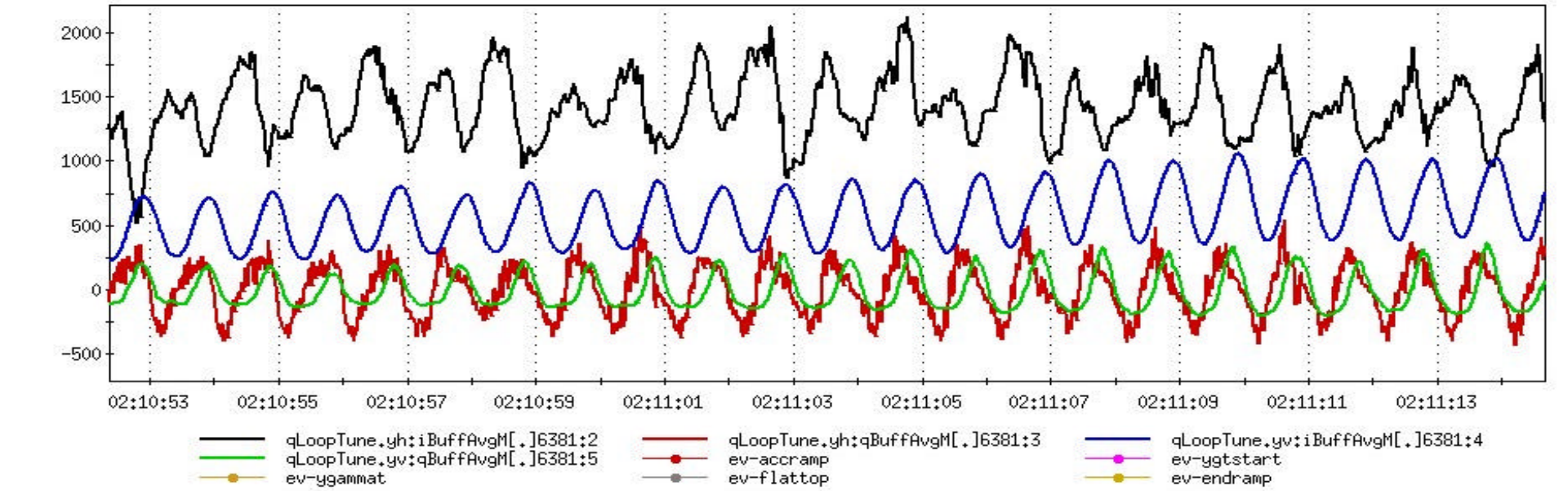
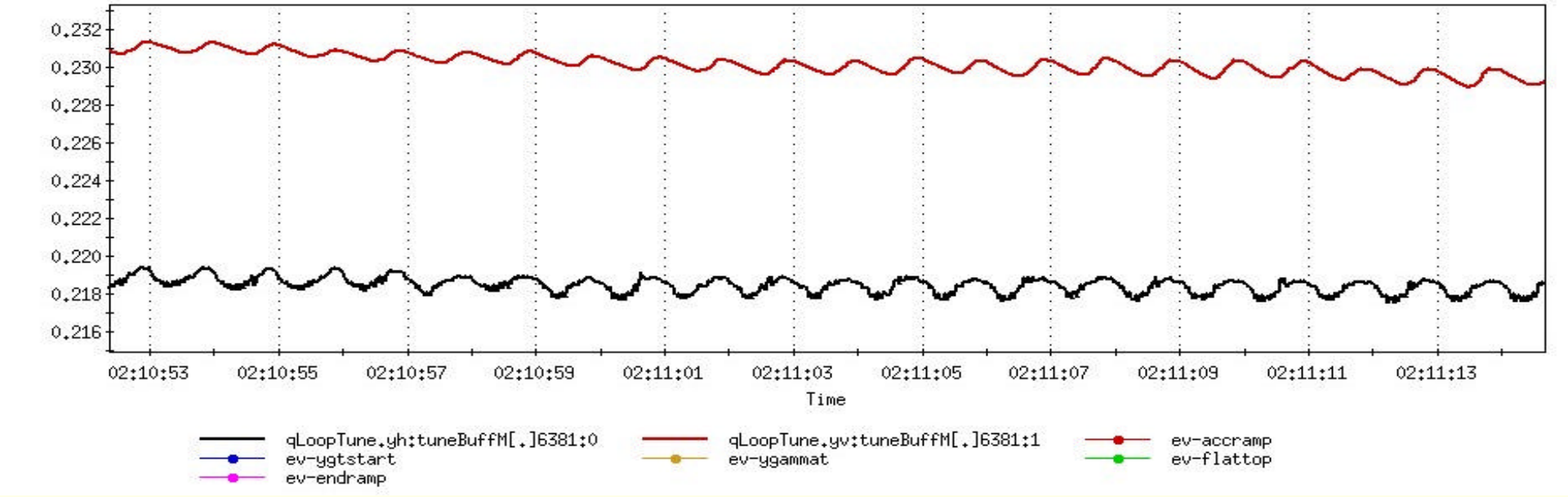
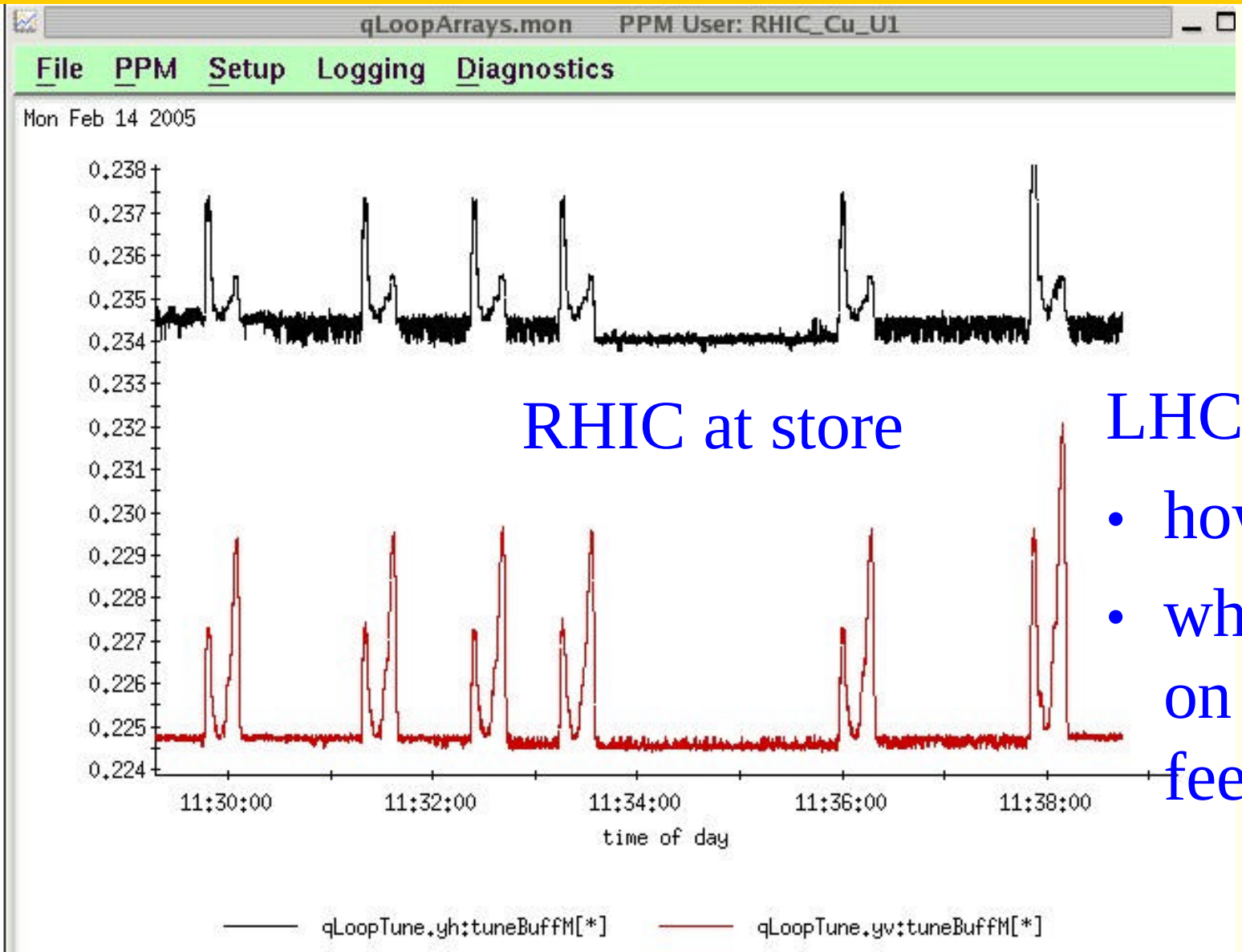




Chrom Refinement

- Measurement 'runaway' scenario
  - significant PLL phase error during chrom measurement
  - chrom correction too small
  - tune mod due to chrom larger than previous measurement, phase error larger, chrom error larger
  - repeat
- The fix
  - use more than depth of tune modulation in chrom correction
  - include PLL phase error in chrom correction

non-linear Chrom?



RHIC at store

LHC

- how big Q"?
- what is effect on chrom feedback?

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Chrom Conclusion

- Chrom spec is actually a spec on ability of tune measurement to track modulation due to chrom, in the presence of other sources of tune modulation (preference is to not have modulation for coupling measurement)
- Baseband sensitivity to chrom may be stronger than what we see in 245MHz system - full momentum distribution is excited
- Inclusion of phase error in chrom correction is essential, will be tested at RHIC asap
- Examine effect of non-lin chrom
- Preliminary indication is that we can meet the spec

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The Coupling Spec

- Does it adequately address the needs of Tune Feedback?

Coupling Conclusion

- Coupling correction is essential for tune feedback
- Sufficient attention has not yet been given to this problem
- Coupling must be measured on the ramp
  - best method is to measure eigenmode projections?
- Coupling feedforward is essential, at least until it is under control.
  - Does this require additional PLL receivers?
- Interface between eigenmode buffer from latest ramp to ramp manager for next ramp must be in place - this is a CERN responsibility
- Possibility of coupling feedback merits investigation?

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The Emittance Spec

- some fraction of 2% during physics running
- considerably more than that during commissioning and machine development

Summary of emittance growth

Difficult to draw accurate conclusions (many parameters), but consensus is

- At 100mW kicker power PLL makes measureable contribution to emittance growth
- At 10-20mW it's hard to see any difference
- Preliminary data from FNAL leads to similar conclusion
- 245MHz system is on the edge in this regard, but only due to dynamic range problem
- presently don't anticipate difficulty here

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60Hz problem

- what are limits of filtering? requires extensive investigation
- Problem is potentially much more serious at LHC - more 60Hz present at 3KHz than 18KHz
- Not yet certain this is on the beam
- Source requires extensive investigation at BNL - localization, possible power supply remediation
  - Beam test of 720Hz balancing
  - Beam test by varying coupling - dipole bus
  - Beam test by off momentum measurement with minimized chrom - quad bus
- Requires extensive investigation at CERN, to minimize the effect before it appears
- Cannot be corrected globally?

Filtering

Filter (simplest would be 60Hz averaging)

- requires lock to (fluctuating) line frequency? h=300 in RHIC
- Limit on PLL BW? Is this a problem?
- Blind spots? Loop gain/dither overcomes this?
- Implications for digitizer clock? From RF? tune? 60Hz?

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The Damper

- Damper sensitivity ~ 1 micron
- PLL requires ~20dB S/N for reliable operation
- BBQ sensitivity requirement is then ~100nm
- We look OK here
- Again, requires further investigation and testing both at CERN and at BNL - machine experiments

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Orbit Feedback

- Is the 2Hz solution to ~ 100 micron chrom modulation acceptable?
- At some level, this defeats purpose of orbit feedback. What is effect on machine protection, collimation,...?
- Requires further investigation at CERN end

Summary/Action Items

- 60Hz
- Coupling
  - better spec
  - measurement and correction method (robust possible?)
  - interface to Ramp Manager for feedforward
  - feedback?
- Chromaticity
  - include PLL phase error in feedback loop
  - magnitude and effect of non-linear chrom
- tune - interface to ramp manager for feedforward
- Damper - confirm BBQ resolution < 100nm
- Orbit Correction - confirm 2Hz operation acceptable